A Novel Educational Proposal: Devising an Electric Power System.

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I. INTRODUCTION

Promoting motivation and engagement among students in a subject is considered as the key aspect that allows better and more efficient learning. For this reason, this type of practice has been introduced at the implementation of the European Higher Education Area (EHEA) in 2010. The case of technical sciences and engineering studies deserves special interest since their intrinsically complexity often requires dedicating most of the class time to theoretical description of the fundaments and working principles and rarely allows promoting students' participation.

In the field of Electrical Engineering, the study of different technologies concerning "Renewable Energies", "Electric Drives", "Efficiency" and "Electricity Markets" is usually approached by computer simulations or virtual laboratories [1]-[3], because any practical exercise is too complex to be implemented.fr

In this paper, the development process of a new subject called "Devising an Electric Power System" is presented along with the results obtained after the first year of implementation in 2014-15. This new subject was regarded as an opportunity to change traditional teaching-learning procedures within the electrical engineering area.

Fully based on laboratory work, the idea of the subject was to conceive a physical platform that would allow students to learn through innovation and experimentation and to have the opportunity to test improvement at any time. The strengths of the new methodology joins the laboratory work (learning by "doing" instead of only by "listening/studying") with the innovation to improve the physical systems and their control.

The device developed by the electrical engineering staff includes a solar PV generator and a pumping controlled drive, both connected to a three-phase electric grid as it is shown in the Fig. 1.

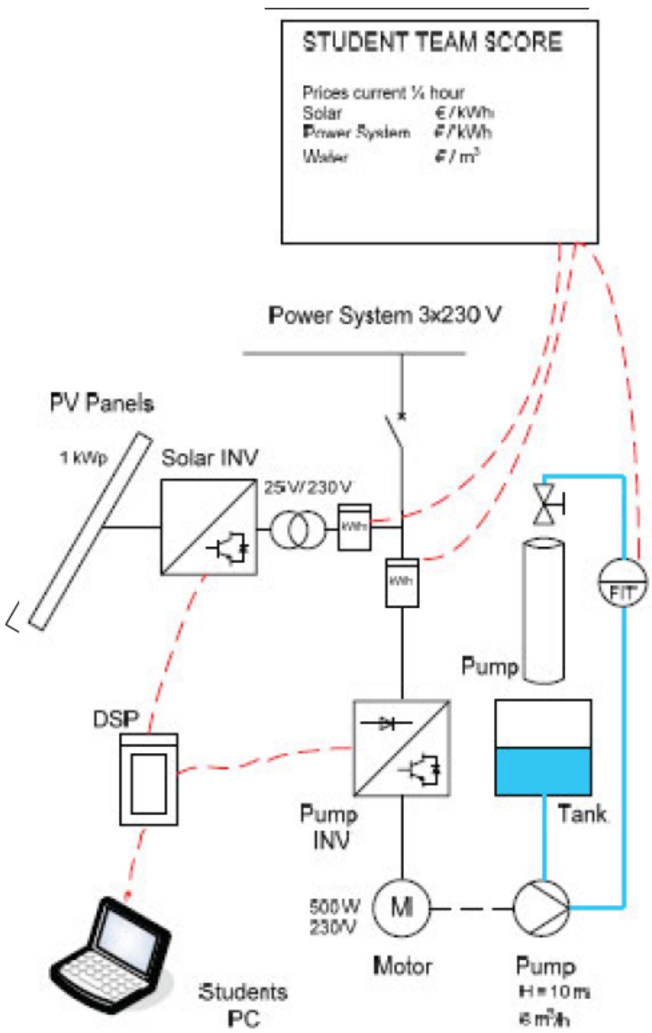

Fig. 1. Simplified single diagram of the student power system for the subject "Devising a power system".

By using this laboratory setup, the students can conceive and design control strategies. For example for solar PV generator the implementation of the Maximum Power Point Tracking "MPPT" are performed by the students. On the other hand different motor control strategies as voltage/frequency strategy or a vector control are done in order to optimize the operation of the pump.

In addition, this laboratory setup allows the students to comply with the rules of the electric utility market by offering energy packages to be generated and consumed at a given price. Once the price is fixed according to the marginal pricing model, the team that comes up with the best offers and best follows their energy generation/consumption commitments will be chosen as the winner in the final competition at the end of the course.

II. Context of the course "Devising an Electric Power System"

The Master Degree in Industrial Engineering offered at ETSII-UPM Madrid is the result of the implementation of Bologna process. The academic implementation took place in the academic year 2014-15. The Master Degree at ETSII is a two year program with 120 ECTS credits, after a four-year Bachelor degree in Industrial Technologies with 240 ECTS credits, with a new subject called INGENIA, linked to the Spanish term "ingeniar" (to provide ingenious solutions) and etymologically related in Spanish with "ingeniero" (engineer).

INGENIA subjects, which are offered in the first course of the Master degree, use project-based learning methodologies following the CDIO approach. Therefore, their structure promotes learning the fundamentals and advanced disciplinary contents of engineering in a practical environment and, at the same time, improving students' motivation and engagement with their own learning process.

The principle that defines INGENIA subjects is to guide the students starting from the conception and design, up to the implementation and operation of a project, system or product in the field of engineering. All the steps previously mentioned would have to comply with a series of requirements previously defined. Students will be given the opportunity to work in real conditions similar to the ones they could encounter in the field. Therefore, students have to work in teams, decide what information they need, find and manage the information, organize the work and communicate the results obtained, all in an efficient way.

INGENIA subjects are compulsory for all students and have 12 ECTS credits, which correspond with student workload between 300 and 360 hours, distributed along two semesters, with 14 weeks per semester. The distribution of this workload is the following: 120 hours correspond to supervised work, that is, work performed under teacher supervision, and between 180 and 240 hours which is allocated for group work.

The supervised work is divided into three categories:

- 30 hours dedicated to the explanation or adaptation of the basic theoretical knowledge to carry out the project.
- 60 hours for practical implementation in the laboratory.
- 15 hours for transversal competences. Several seminars and workshops are offered to students to acquire and improve team building, communication and creativity skills.
- 15 hours for social responsibility issues, such as, environmental impact and consequences of the project in social, political, security and health areas. All projects must include a study of this type.

Lectures, laboratory and seminars with teacher supervision are spread in 5 hours per week.

Several departments of the ETSII-UPM have carried out INGENIA proposals related with diverse disciplines such as: electronic and automation, electrical, automotive, mechanical and biomedical engineering. There are 11 different INGENIA subjects and the students must choose one of them.

INGENIA course "Devising an Electric Power System" has been developed by Electrical Engineering instructors (Electrical Machines and Electric Power systems) and Statistics instructors. Most of the students who have chosen this subject have electrical and energy specialty, so they have basic knowledge of electrical machines, power electronics and drives. Twelve teachers have participated in the subject and most of them have previous experience in CDIO activities [4], and belong to two different Innovation Education Groups at the UPM university having participated in several educational innovation projects, [5]-[9].

The subject aims to provide an insight that integrates the most important and innovative advancement in electrical engineering and promote the capability for designing and implementing an electric power system with both generation (photovoltaic panel) and consumption (pumping electric drive), and at the same time operating under the rules of an electricity market.

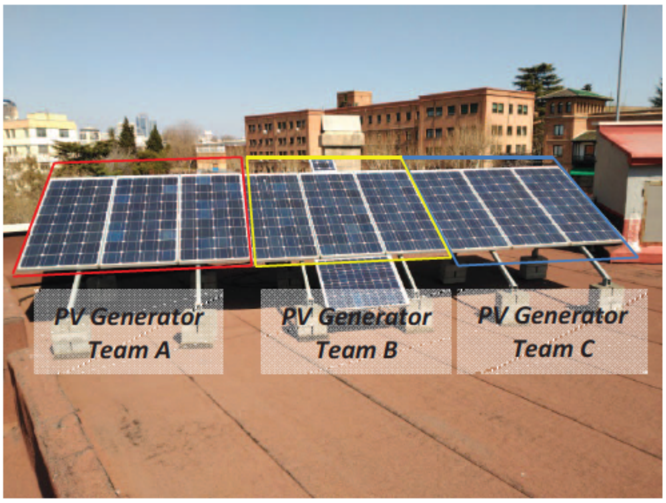

Fig. 2. Photovoltaic Generators for the three students teams, installed in the roof of the University.

III. Description of the Course

The maximum number of student admitted in the course is 21. Table 1 shows a summary of the main characteristics of the course.

The students are divided into three teams and each one has to work on a laboratory setup that includes a solar PV generator and a pumping controlled drive, both connected to a three phase electric grid. Thus, the hardware the students deal with, includes mainly a laptop connected to a DSP, two power converters Solar Inverter (Solar INV) and Pump Inverter (Pump INV), as it is shown in the Fig. 1. The Solar Inverter is a DC/AC converter that connects the PV generator to the grid. On the other hand the Pump Inverter is a AC/AC converter that feeds the pump motor from the grid. The PV generators are located in the roof of the University as is shown in the Fig 2. All the PV generator are similar and have the same orientation in order to supply the same energy to the three teams.

TABLE 1. MAIN FIGURES OF INGENIA COURSE "DEVISING AN ELECTRIC POWER SYSTEM"

Students		Teachers		
Total number	Number of groups	Type	Number	Workload
21	3	Supervised work	12	90 hours
Number per group	7	Transversal skills	4	30 hours

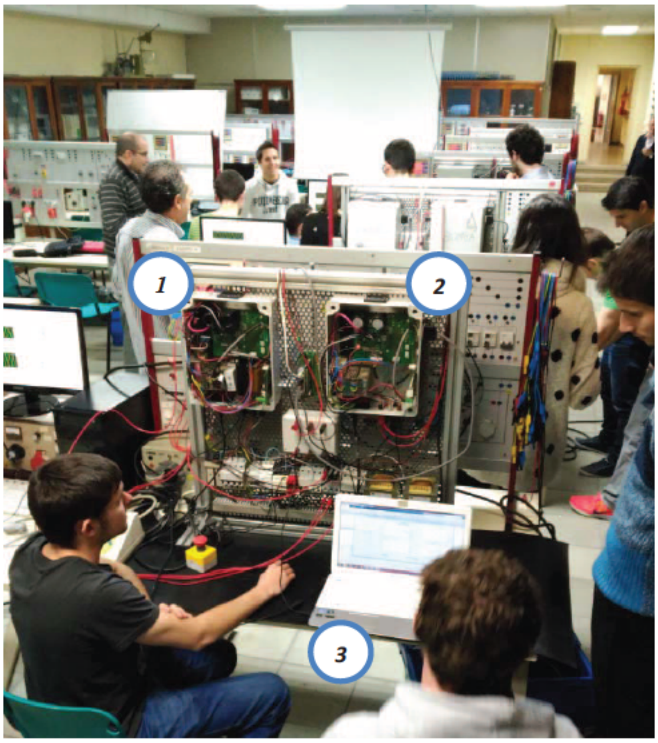

Fig. 3. Students competition. 1 Solar Inverter; 2 Pump Inverter and 3 Students control PC.

Water flow, current and voltage sensors and energy measurement devices are also installed for control purpose as well as for the competition.

Although the subject lasts one whole course, it is divided into four two-month periods.

The first one is used to introduce the basic theoretical contents of each topic in the subject (PV generation, power electronics, pumping installations, control of electric drives and the hardware platform the students will use during the course). All these theoretical contents are faced along with the physical systems being in front of the students, so as the students can learn quickly the working principles of each device in the system.

The second two-month period is used to perform laboratory tests of each component of the system. For example the non-load and locked rotor test of the asynchronous motor, the pump operation at different speeds, the PV generator I/V curves, etc.

So as to acquire a deep knowledge and characterize them in order to be able to improve them or to take into account their particular behavior for the next innovation stage.

The third period consists of different partial competitions each one concerning only one system. The first partial competition is related to the PV generation. The teams have to generate the maximum electric energy during ten minutes. The second partial competition is related to the pumping system. The objective is to supply a certain water flow with the minimum energy consumption.

In order to prepare each event the students must face a creative practice in which innovative competences are trained. This way the subject allows the students, for example, to learn about the grid connection of a PV generator and to program the Maximum Power Point Tracking "MPPT" along the sun day, by innovating and practicing with a real installation together with the motivation of a teamwork facing a contest. In this period, predictive models of PV generation, which are prepared by the students under the supervision of experts in statistics, are also used in order to improve the success options for the competitions.

The fourth and last two-month period deals with the study of electricity market rules. The complexity of this discipline itself makes it especially difficult to be taught by using real equipment instead of only simulation models. In this way, the subject that is being described is innovative, since it allows the students to learn this matter again by practicing, being conscious, for example, of the difficulties in real life of predicting the energy demand, the renewable resource, etc.

Finally a competition between the three teams takes place in the final day of the course, as it is shown in the Fig. 3.

The three main disciplines the subject deals with are the PV generation, the pumping facilities and the electric markets. Each of them with be treated separately in the next sections of this subject description.

A. Solar PV generation

Each group of students have a solar PV system that comprises three PV panels connected in series, with a total rated voltage of 48V, a three-phase DC/AC converter as a solar inverter, some current filters and a three-phase transformer 25/230V to connect to the grid, since the low voltage range of operation at the PV panels require a low AC voltage to work properly. The students carry out the different stages to do the starting up of the solar inverter. They previously test the inverter supplying a passive load, firstly in open loop and secondly controlling the current in closed loop. Then, they connect the DC voltage supplied by the panels to the grid, by using a voltage reference value which is obtained every moment from the algorithm of maximum power point tracking "MPPT".

The solar inverter commutations are controlled by means of space vector modulation "SVM" technique, ensuring a better harmonic distortion and the possibility of over-modulating.

Both the MPPT algorithm and the inverter commutation are implemented in the system into a commercial digital signal processor (DSP), a F28335 from Texas Instruments©. The code is introduced in C-language and there is an instrumentation environment, MATLAB GUIDE, in order to represent the different waveforms, mainly the DC-link voltage and the line currents supplied to the grid. Fig. 4 shows the instrumentation environment developed with MATLAB, allowing to modify parameters and to obtain the main variables from the system.

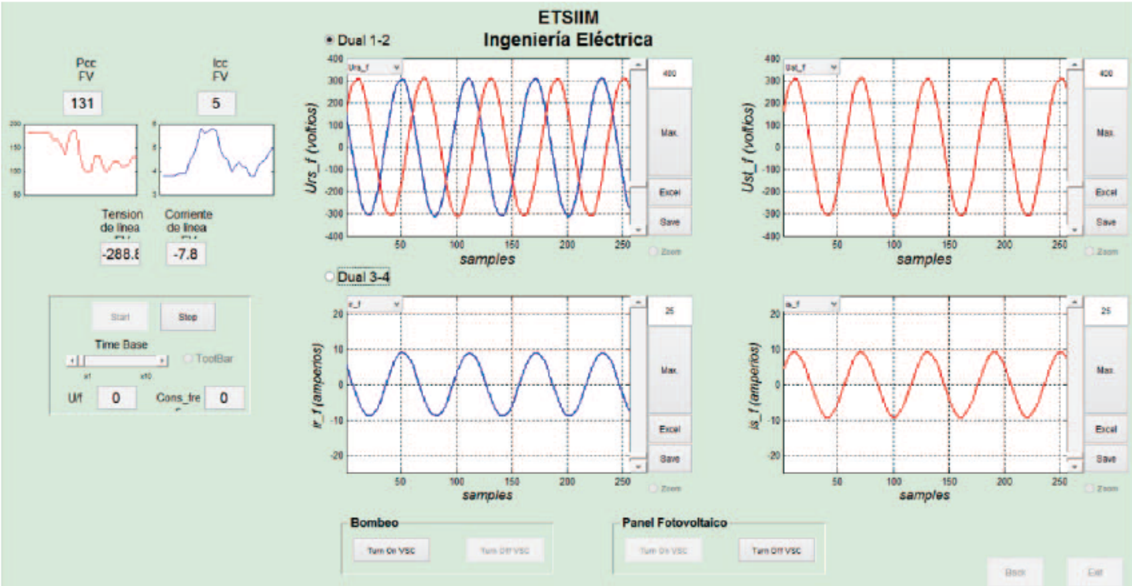

Fig. 4. Screenshot of the Matlab interface showing the grid connection of the PV generator and the search for the MPPT

B. *Pumping installation*

In order to teach students in the control of electric drives, a pumping installation has been chosen both to innovate around efficiency concerns and as an example to represent an electric load for each team when acting as an electric utility with generation and consume in the final contest. These installations allow measuring the pumped water to compare the efficiency and also to get "money" for the final completion according to the market.

Two different types of pumps are available and each team should test them in advance in order to know which one would fit better the performance required in each competition. Different criteria will be used according to the water flow and the energy consumed requirements, making each team to look for the best solution and to take strategic decisions in a short time manner. With respect to the motor control techniques the student are free to use a simple scalar control (open loop V/f) or a more sophisticated alternative (vector control with speed estimation). The inverter is controlled again through the DSP system using SVM technique.

The pumping setup includes, for each team, a water tank, flow and pressure measurement devices, and a calibrated deposit which allows seeing and measuring the amount of pumped water.

The different pumps should be tested at different speed in order to know their parameter for preparing the control strategy, to get maximum flow or maximum efficiency.

It is also important to test the electric motor in order to obtain the losses and to have the equivalent circuit values, also necessary to design the control strategy.

In Fig. 5, a picture of the pumping installations for the three teams is shown. The water flow indicator and transmitter FIT as place in the supports. The supports are adjustable and the gross head of the pumping system could be modified within a range of 2 – 3.25 meters. The gross head of the installation could be change in the final completion.

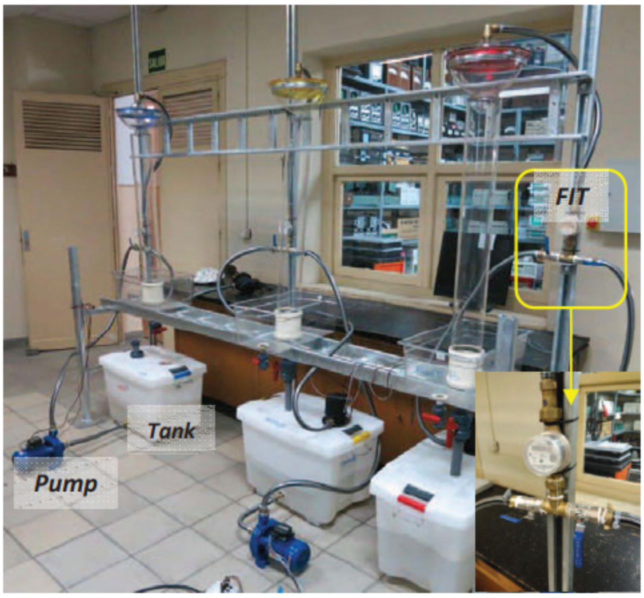

Fig. 5. Three pumping installations for the three teams

C. *Electricity markets contest*

As a part for the development of the various objectives of the course, an electricity market simulation game is proposed. In this game, each of the three teams assumed the role of a utility that integrates a generation business and a large electricity consumer, as well as a water supplier. The firm participates with two agents, a generator and a large consumer, in a competitive electricity market. In addition to these six participants, there is a seventh agent, the system operator, assumed by the instructor, whose role is to ensure proper operation of the power system. To do this, the system operator has an additional reserve generation or consumption, physically implemented as a connection to the external 50 Hz power supply. The market operator is also the instructor.

For each session of the competition, all the agents participate in the market with at least ten different offers or bids each. In a first step, the offers from generators are matched to the bids from consumers, using an algorithm developed in Matlab, and the clearing price is determined as the intersection point between aggregated curves. A picture of the laboratory screen taken during a session can be seen in Fig. 6. According to a marginal pricing model, this price is paid to all generators with cheaper offers, which are committed to supply the corresponding energy blocks. Similarly, all consumers with higher bids pay the clearing price and are obliged to use their corresponding energy amounts.

Once the market session is cleared, the second step is the physical operation of the power system with the developed real equipment. The agents try to do their best to meet their energy commitments but, as in the real world, this is not always possible and some deviations occur. All the energy interchanges are measured and recorded.

In the final step of the session, the market operator proceeds to the liquidation of the energy blocks actually generated or consumed, taking into account the marginal pricing model and the settlement of deviations.

The goal for every company is to obtain maximum profits after a predetermined number of sessions. To do this, the groups integrate income and expenses of their generator and consumer agents. Obviously, the implementation details of the game are designed with the aim that a good result is the consequence of a good job of prior design, construction, and testing of the developed generator and consumer devices.

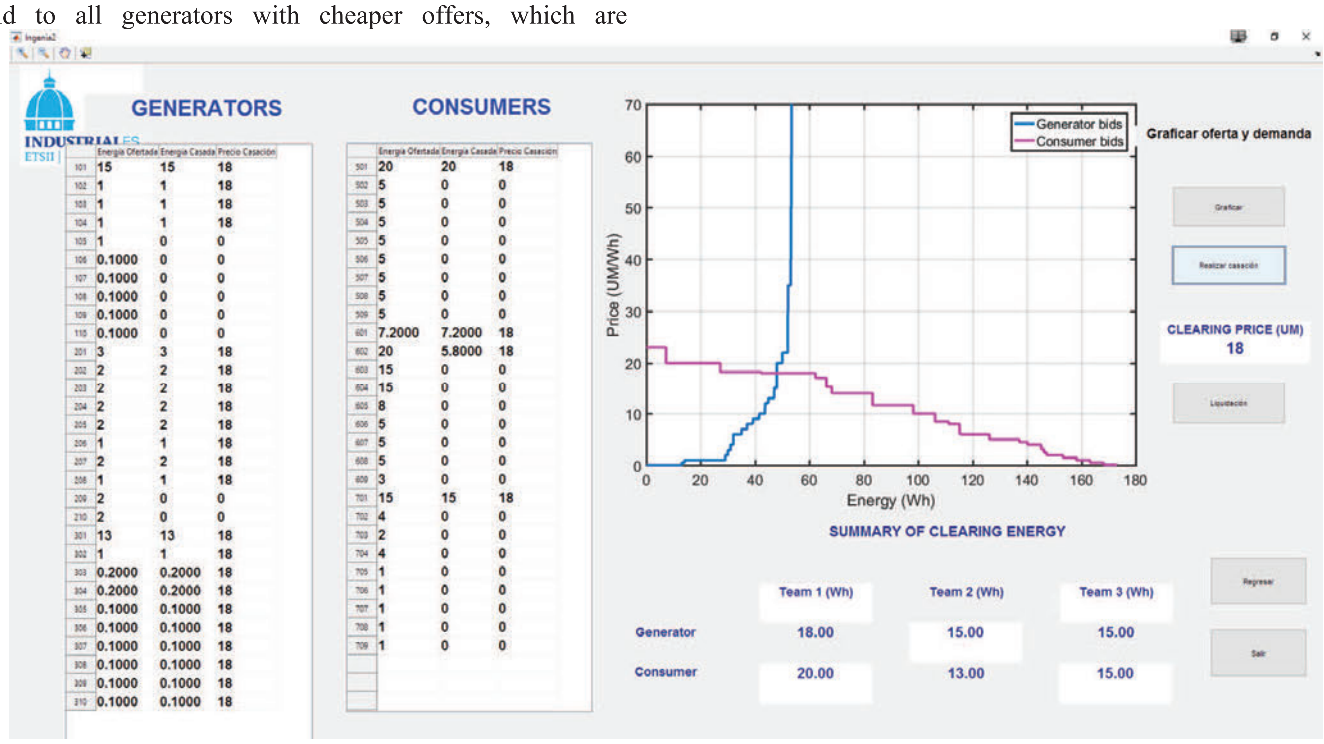

Fig. 6. The price and volume of energy are determined by matching offers from generators to bids from consumers

IV. Results

The described INGENIA course “Devising an Electric Power System”, to the authors’ knowledge, is the first course held in Spain that complete a CDIO cycle in the field of Electrical Engineering with laboratory and practical implementation which includes not only the generation and demand of an electric power system, but also carrying out an electric market.

The results obtained have been highly satisfactory for teachers and students. Teachers have proved that the new learning methodology carried out helps the students in understanding the theoretical principles, and the physical implementation favors their comprehension and learning. The success ratio (student completion rate) has been 100%, significantly superior to the one obtained in conventional subjects within the electrical area, which is usually between 70% and 80%.

In the case of the students, the course has provided them with the “conceive-design-implement-operate” teaching-learning activities, which include the acquisition of transversal skills such as team work, communication and creativity.

At the end of the course the 100% of the students answered a questionnaire that asked them about their overall assessment of the subject, as well as about each of the modules in which it is divided. Table 2 summarizes the most relevant students' answers to this questionnaire. The consideration about their improvement in supervised work and global consideration of the course is significantly good, however, the results obtained in the part of improvement in transversal outcomes are lower than those obtained in the part of supervised work. Transversal skills acquisition modules represent an educational innovation in the electrical engineering of the ETSII experience. General courses on transversal outcomes were offered so students could learn how to work more efficiently in groups and to improve their techniques in public expositions, carrying out individual presentations. However, it has been necessary change the methodology of transversal skills acquisition. During the 2015-2016 course it has been worked individually with each INGENIA course, within the ETSII, adapting to their own peculiarities and trying to reinforce transversal skills by introducing practical sessions rather than theoretical presentations.

TABLE 2. RESULT OF STUDENT QUESTIONNAIRE

Question: What is your consideration about…..?		**Subject on Devising an Electric System**	**Typical deviation**
The whole course		4,48/5	0,6
Improvement in Supervised work	Conceiving	4,25/5	0,72
	Planning	4,15/5	0,59
	Designing	4,38/5	0,77
	Experimenting	4,95/5	0,22
	Implementing	4,76/5	0,44
	Continuous work	4,48/5	0,68
Improvement in Transversal outcomes	Team work	4,10/5	1,22
	Communication	3,65/5	0,93
	Creativity	3,30/5	0,98
Social responsibility Teacher contributions		3,52/5	1,12
Student comments			
Doing more subjects like INGENIA, is the way to learn better and more The subject requires great amount of work but it is worth it Better planning of the subject to deep in the electricity market			

As an overall conclusion of the results obtained in the first year implementing this new subject, it is important to highlight that the students also included personal comments in the questionnaire that pointed out their high motivation and engagement with the subject.

V. Conclusions

A new subject called "Devising an Electric Power System" has been presented including its conception, the development along the course and the results obtained after the first year of implementation in 2014-15. Following the CDIO concept and fully based on laboratory work, the starting point for this experience was to conceive a physical platform which would allow the students to learn through the innovation, all facilitated by the ability of testing any improvement any time is needed. The strength of the new methodology presented is putting together the laboratory work (better "doing" than only "listening/studying") and the capacity of innovation applied to improving a physical system and its control.

In the course "Devising an Electric Power System", a hybrid simulation-reality game is proposed by simulating electricity markets integrated with an actual power system, in which the emphasis is put on the conception, design, implementation, and operation of a real system and its components. The integration of this real system into the game, in addition of serving as an incentive to the student and an assessment method of the developed work, aims to provide the mere engineering tasks with an orientation towards meeting customer needs while considering resource constraints.

VI. Acknowledgment

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